MICRONAS

Hardware
Documentation

Data Sheet

CUR 4000

High-Precision Multi-Hall-Array Current Sensor

curSENS Technology

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Contents

High-Precision Multi-Hall-Array Current Sensor

Note **Revision bars indicate changes compared to the previous edition.**

1. Introduction

CUR 4000 is a member of TDK-Micronas' current sensor portfolio, providing the flexibility of high-resolution linear current measurement as well as stray-field compensated differential current measurement. The sensor can measure both AC and DC running through a conductor rail. CUR 4000 is available in the 8-pin SOIC-8 package which is suitable for soldering on a PCB. The current is measured via the intensity of the magnetic field generated by the current flow. Depending on the type of current measurement, two system setups are possible:

High-resolution linear current measurement: A C-core made of soft magnetic material is placed around a conductor to concentrate the magnetic field. The Hall sensor is mounted on a PCB which is placed in the small air gap of the C-core.

Stray-field compensated differential current measurement: The sensor is mounted either above or next to the conductor rail, integrated in the PCB. Thanks to the differential Hall plate setup, external shielding is usually not required.

The Hall sensor's output is proportional to the current in the conductor and transmitted via the sensor's SPI interface. The measurement data is provided as 16-bit value and thanks to an integrated temperature sensor, the output signal is already temperature-compensated by the device itself.

In addition, a Low-Power mode is available. An external ECU can send the device into Low-Power mode. The device wakes up periodically and provides measurement data in the active phase. The sensor can also wake up the external ECU in case that the magnetic field exceeds a programmable threshold.

Major characteristics like gain and offset can be adjusted to the magnetic circuitry by programming the non-volatile memory. Additional output signal linearization is possible by using up to 17 setpoints with variable distance or 33 equidistant setpoints.

The non-volatile memory of the device is programmable via the SPI interface.

This product is defined as SEooC ASIL B ready (Safety Element out of Context) according to ISO 26262.

The device is designed for automotive and industrial applications. It operates in the ambient temperature range from –40 °C to 150 °C.

The sensor is available in the 8-pin SOIC SMD package.

1.1. Major Applications

Due to the sensor's versatile programming characteristics and its high accuracy, the CUR 4000 is a potential system solution for the following application examples:

– High-precision linear current sensing (core-based)

– Differential stray-field robust current sensing (core-less)

1.2. General Features

– High-precision linear current sensing with an array consisting of six Hall plates (core-based application)

– Differential stray-field compensation (core-less application)

– SEooC ASIL B ready according to ISO 26262 to fulfill Functional Safety requirements

– Supply voltages between 3.0 V and 5.5 V

– SPI communication up to 5 MHz

– 16-bit data transmission with CRC, status bits, and rolling counter

– Up to 8 kSps sampling frequency

– Operates from –40 °C up to 170 °C junction temperature

– Programming via SPI interface

– Various configurable signal processing parameters, like output gain and offset, temperature-dependent offset, etc.

– Programmable arbitrary output characteristic with 17 variable or 33 fixed setpoints

– Programmable characteristics in a non-volatile memory (EEPROM) with redundancy and lock function

– Read access on non-volatile memory after customer lock

– On-chip diagnostics of different functional blocks of the sensor

– Several Low-Power mode configurations (see Table 3–9)

2. Ordering Information

A Micronas device is available in a variety of delivery forms. They are distinguished by a specific ordering code:

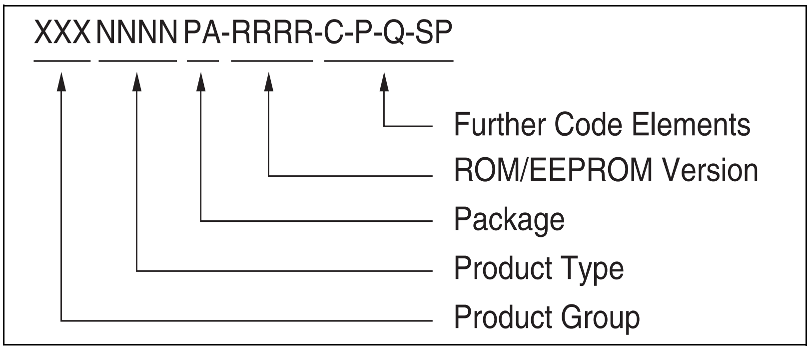


Fig. 2–1: Ordering Code Principle

For a detailed information, please refer to the brochure:
"Sensors and Controllers: Ordering Codes, Packaging, Handling".

2.1. Device-Specific Ordering Codes

The CUR 4000 is available in the following package and temperature variants.

Table 2–1: Available package

Package Code (PA)	Package Type
DJ	SOIC-8

The relationship between ambient temperature (T_A) and junction temperature (T_J) is explained in Section 6.1. on page 40.

For available variants for Configuration (C), Packaging (P), Quantity (Q), and Special Procedure (SP) please contact TDK-Micronas.

Table 2–2: Available ordering codes and corresponding package marking

Version	Available Ordering Codes	Package Marking	Package
Linear (Multi Hall Plates) current sensing	CUR4000DJ[0000]-[C-P-Q-SP]	A4000[0000] Lot Number Date Code SB	SOIC-8
Differential or Linear (Dual Hall Plates) current sensing	CUR4000DJ[0001]-[C-P-Q-SP]	A4000[0001] Lot Number Date Code SB	SOIC-8

3. Functional Description

3.1. General Function

CUR 4000 is a current sensor based on Hall-effect technology. The sensor includes an array of horizontal Hall plates based on TDK-Micronas' HAL technology. The array of Hall plates has a diameter C of 2.25 mm (nominal).

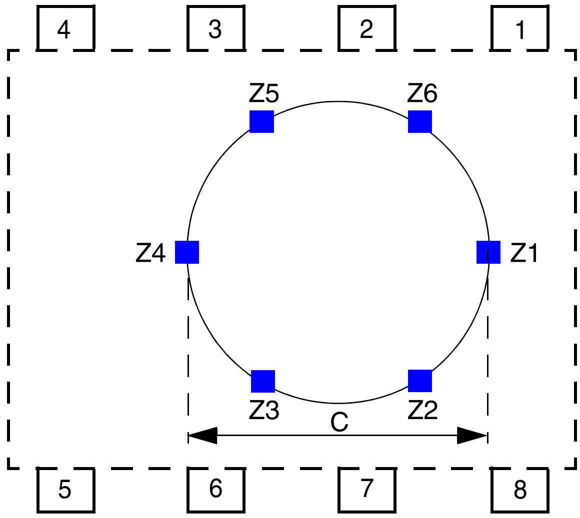


Fig. 3–1: Hall-plate configuration for CUR 4000

The Hall-plate signals are first measured by A/D converters, filtered and temperature compensated. A linearization block can be used to reduce the overall system non-linearity error (available in Z4–Z1 or Z4+Z1 measurement setup).

On-chip offset compensation by spinning current minimizes the errors due to supply voltage and temperature variations as well as external package stress.

The sensor supports two measurement configurations:

– Measurement of six Z-plates for precise linear current measurement

– Differential current measurement with stray-field compensation (Z4–Z1)

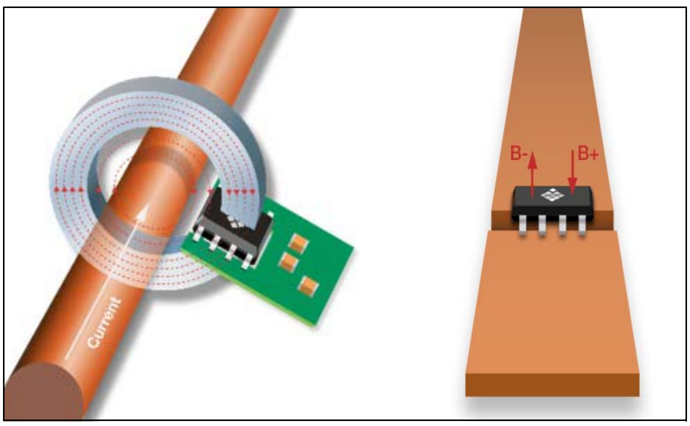


Fig. 3–2: Core and Differential application setup

Overall, the in-system calibration can be utilized by the system designer to optimize performance for a specific system. The calibration information is stored in an on-chip memory.

The sensor features a 4-wire SPI (Serial Peripheral Interface) to get access to the sensor memory as well as to the measurement results. CUR 4000 operates as an SPI slave only. Each data transfer is full duplex for simultaneously read/write commands to the sensor while collecting the response from the former request.

The CUR 4000 is programmable via the integrated SPI. No additional programming pin is needed and fast end-of-line programming is enabled.

CUR 4000 features two kinds of operational modes. Application Mode and a Low-Power Mode. In Application Mode, the sensor is continuously measuring the magnetic-field strength proportional to the current flow in the conductor rail and an ECU can poll the measured information. In Low-Power Mode, the sensor is in a Sleep Phase for a certain time and shortly in Active Phase to capture measurement data. During Sleep Phase, the current consumption of the device is significantly reduced. All different Low-Power Mode configurations are described in Table 3–9 on page 23.

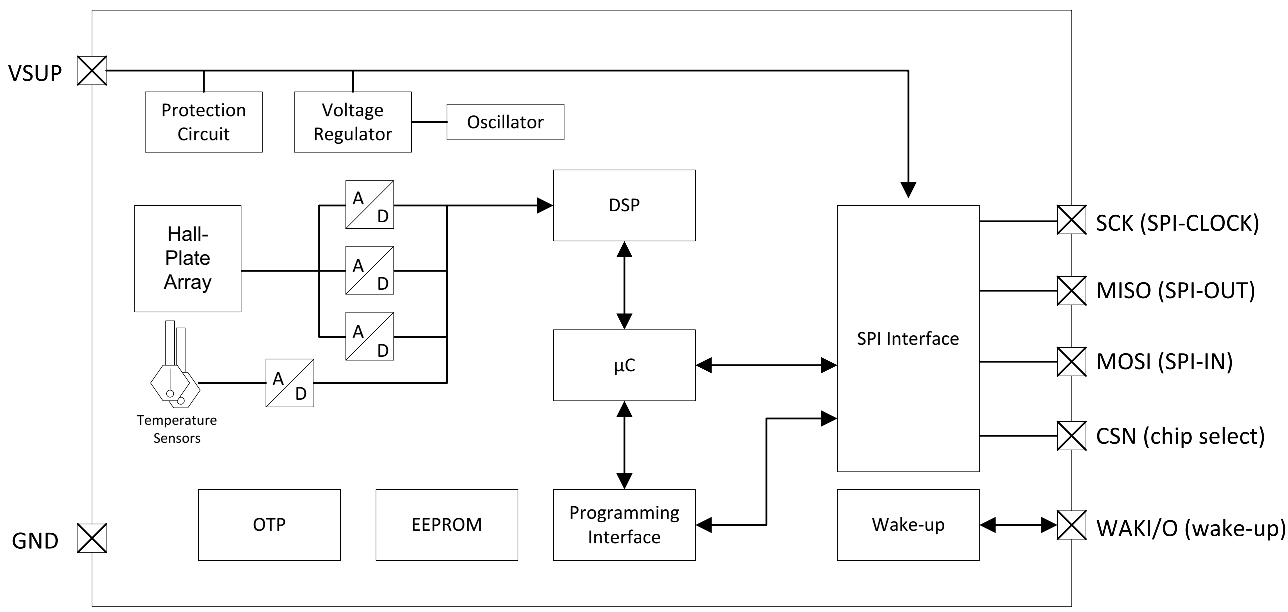


Fig. 3–3: CUR 4000 block diagram

3.2. Signal Path

The DSP part of this sensor performs the signal conditioning. The parameters for the DSP are stored in the memory registers. Details of the overall signal path are shown in Fig. 3–4.

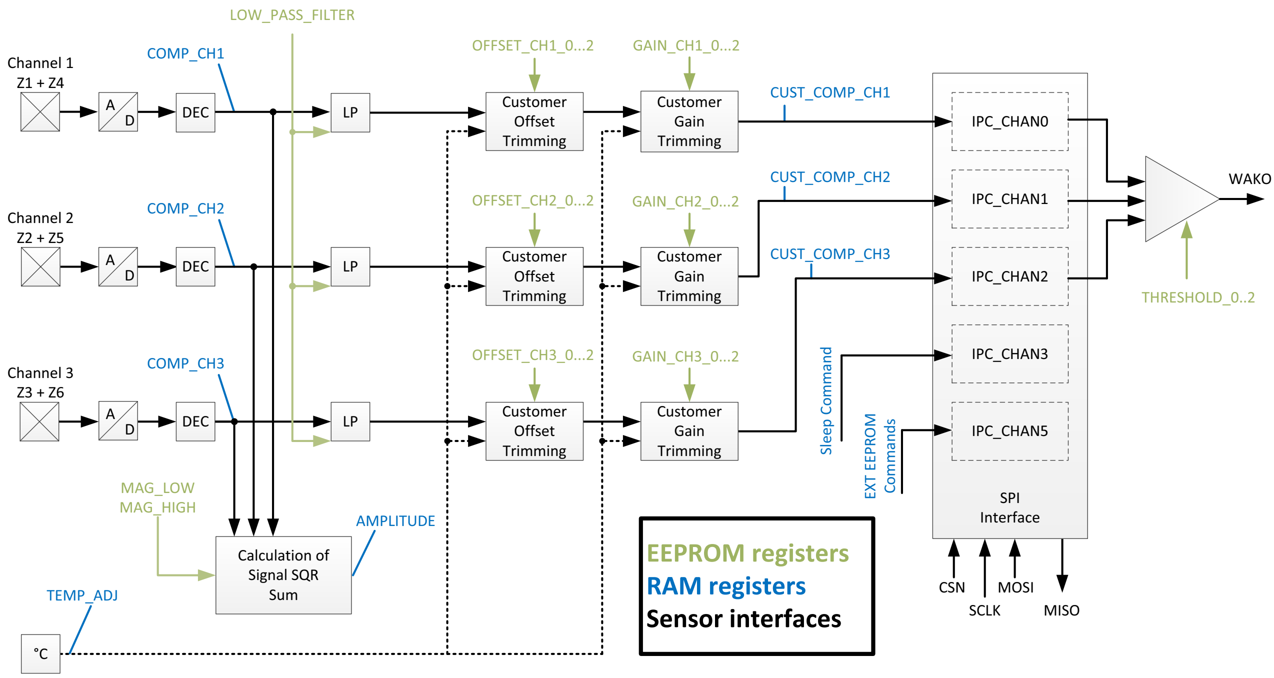


Fig. 3–4: Signal path of CUR 4000 6Z (linear current measurement)

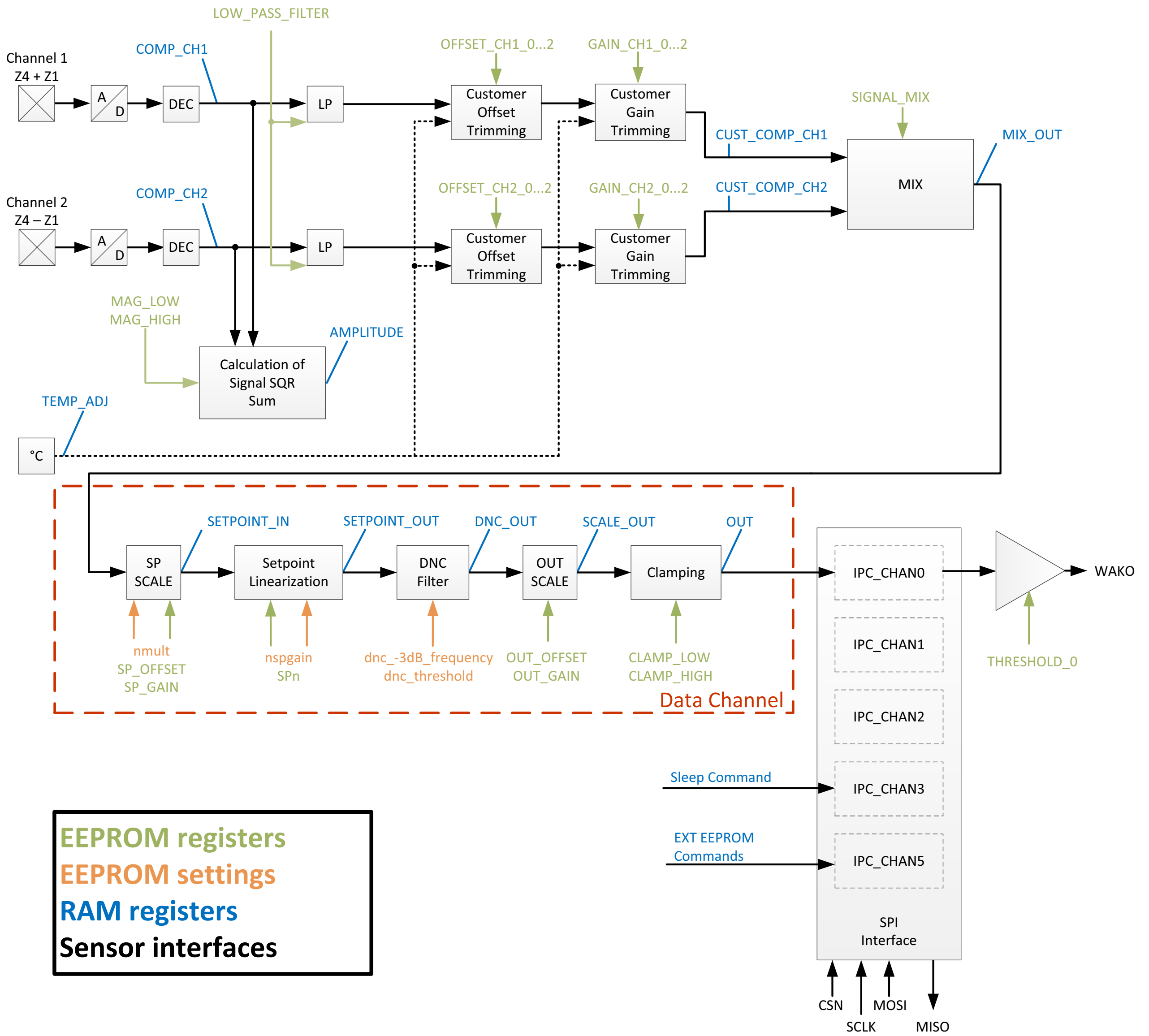


Fig. 3–5: Signal path of CUR 4000 2Z (differential current measurement)

The sensor signal path contains two kinds of registers. Registers that are read-only and programmable registers (non-volatile memory). The read-only registers contain measurement data at certain steps of the signal path and the non-volatile memory registers change the sensor's signal processing. EEPROM settings are individually configurable bits within an EEPROM register.

3.3. Register Definition

Note Further details about the programming of the device and detailed register setting description as well as memory map can be found in the document: CUR 4000 User Manual.

3.3.1. RAM Registers

TEMP_TADJ

The TEMP_TADJ register already contains the TDK-Micronas' compensated digital value of the sensor junction temperature.

COMP_CH1, COMP_CH2 and COMP_CH3

COMP_CH1, COMP_CH2, and COMP_CH3 registers contain the TDK-Micronas' temperature compensated magnetic-field information of channel 1-3.

Amplitude (only for 6Z measurement setup)

The AMPLITUDE register contains sum of squares of the magnetic field amplitude of all three signals calculated with the following equation. This information can be used for over current detection:

$$\mathrm{AMPLITUDE} = \frac{\mathrm{COMP\_CH1}^2}{32768} + \frac{\mathrm{COMP\_CH2}^2}{32768} + \frac{\mathrm{COMP\_CH3}^2}{32768}$$

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH3

CUST_COMP_CH1, CUST_COMP_CH2 and CUST_COMP_CH3 registers contain the customer-compensated magnetic-field information of channel 1, channel 2, and channel 3. These registers already contain the customer gain and offset corrected data.

SETPOINT_IN (only for 2Z measurement setup)

The SETPOINT_IN registers contain the digital value of the measurement data information after the setpoint scaling block and are the values used for the input of the setpoint linearization block.

SETPOINT_OUT (only for 2Z measurement setup)

The SETPOINT_OUT registers contain the digital value of the measurement data information after the setpoint linearization block.

DNC_OUT (only for 2Z measurement setup)

The DNC_OUT register contains the digital value of the measurement data information after the DNC filter. DNC_OUT is only available for the primary output.

OUT (only for 2Z measurement setup)

The OUT registers contain the digital value of the measurement data information after all signal processing steps and depends on all customer configuration settings.

DIAGNOSIS

The DIAGNOSIS_0 and DIAGNOSIS_1 registers report certain failures detected by the sensor. CUR 4000 performs self-tests during power-up as well as continuous system integrity tests during normal operation. The result of those tests is reported via the DIAGNOSIS_X registers (further details can be found in Table 4–1 & Table 4–2).

Micronas IDs

The MIC_ID1 and MIC_ID2 registers are both 16 bit organized. They are read-only and contain TDK-Micronas production information, like X,Y position on the wafer, wafer number, etc.

Note The above mentioned RAM register can be read in programming mode. For normal application mode, respectively in the running application, only IPC_CHAN0...2 registers must be used. Only those registers are secured via CRC checks and error reporting. Table 3–1 shows the available data.

Table 3–1: Hardware register memory table

Address	Register Name	Function
0x70	IPC_CHAN0	Inter-processor data channel 0 OUT or CUST_COMP_CH1
0x71	IPC_CHAN1	Inter-processor data channel 1 CUST_COMP_CH2
0x72	IPC_CHAN2	Inter-processor data channel 2 CUST_COMP_CH3
0x73	IPC_CHAN3	Inter-processor data channel 3 Send to sleep command
0x75	IPC_CHAN5	Inter-processor data channel 5 For EEPROM memory access and programming or RAM register read
0x78	COMP_CH1	Signal after decimation filter 1
0x79	COMP_CH2	Signal after decimation filter 2
0x7A	COMP_CH3	Signal after decimation filter 3
0x7D	DIAG_0	Diagnosis register 0 (see Table 4–1 on page 28)
0x7E	DIAG_1	Diagnosis register 1(see Table 4–2 on page 29)
0x7F	HW_ID	Hardware ID base

3.3.2. EEPROM Registers

Measurement Setups

CUR 4000 can be configured in different measurement setups. Depending on the required measurement task, one of the measurement setups can be selected. The register SETUP_FRONTEND (see Table 3–3 on page 18) defines the different available measurement setups.

– Setup 6Z: Linear current measurement (core-based application)

This setup uses six horizontal Hall plates to measure the current with higher sensitivity in combination with a magnetic-field concentrator. Fig. 3–6 shows the related signal path.

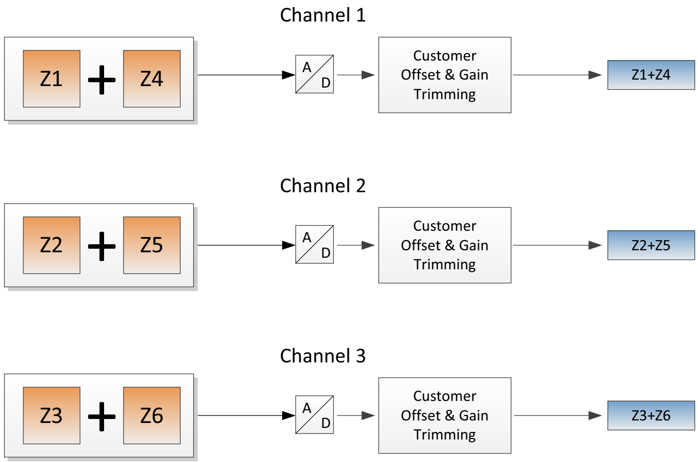


Fig. 3–6: Signal path diagram of Linear current measurement

– Setup 2Z: Differential current measurement (stray-field compensated)

This setup uses a differential setup of 2 horizontal Hall plates (Z4-Z1). The magnetic field current will be to measured core-less with strayfield compensation. The sensor has to be mounted either above or next to the conductor rail. Additional this setup can measure the sum of Z4 and Z1 (Z4+Z1). With the MUX signal selection to the respective input signal can be selected to the output interface.

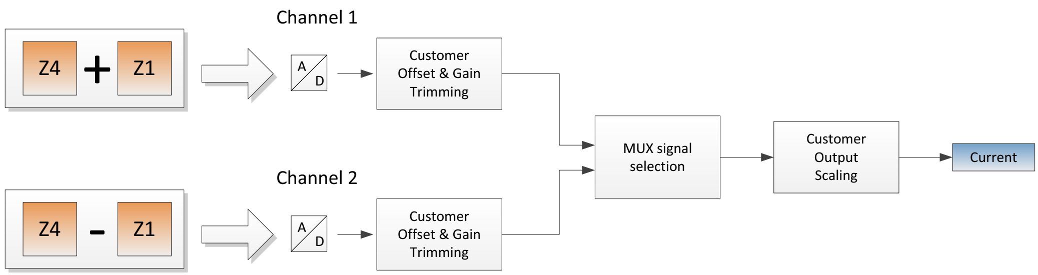


Fig. 3–7: Signal path diagram of Differential current measurement

Customer IDs

The customer ID registers (CUSTOMER_ID0 to CUSTOMER_ID9) contains nine 16-bit words and can be used to store customer production information, like serial number, project information, etc.

Magnetic-Field Range Check

The magnetic-field range check uses the AMPLITUDE register value and compares it with an upper and lower limit threshold defined by the registers MAG_LOW and MAG_HIGH. If either low or high limit is exceeded, the sensor will indicate an error.

Mag-Low Limit

MAG_LOW defines the low level for the magnetic field range check function. The limit can also be turned off.

Mag-High Limit (only for 6Z setup)

MAG-HIGH defines the high level for the magnetic-field range check function. The limit can also be turned off.

Low-Pass Filter

With the LOW_PASS_FILTER register it is possible to select different –3dB frequencies for CUR 4000. The default value is zero (low-pass filter disabled). The filter frequency is valid for all channels.

GAIN_CHx_0...2

GAIN_CH1_0...2, GAIN_CH2_0...2, and GAIN_CH3...2 support three polynomials of second order and describe the temperature compensation of the sensitivity of channel 1, channel 2 and channel 3 (compensating the amplitude mismatches between three channels). This means, a constant, linear and quadratic gain factor can be programmed individually for the three channels (temperature-dependent gain).

OFFSET_CHx_0...2

OFFSET_CH1_0...2, OFFSET_CH2_0...2, and OFFSET_CH3_0...2 support three polynomials of second order and describe the temperature compensation of the offset of channel 1, channel 2 and channel 3 (compensating a remaining offset in each of the three channels). This means, a constant, linear and quadratic offset factor can be programmed for up to three channels (temperature-dependent offset).

nmult (EEPROM Setting) (only for 2Z setup)

nmult defines the gain exponent for the setpoint scaling block on the data channel. The factor is multiplied by SP_GAIN to achieve gain factors up to 128. SETUP_DATAPATH[7:5] bits (= nmult).

Setpoint Gain (only for 2Z setup)

SP_GAIN define the output gain for the primary and secondary channels. They are used to scale the position information to the input range of the linearization block.

Setpoint Offset (only for 2Z setup)

SP_OFFSET define the output offset for the primary and secondary channels.

Setpoint Linearization (only for 2Z setup)

The setpoint linearization block enables the linearization of the sensor's output characteristic for the customer's application. It consists of 33 setpoints (SP0, SP1, ..., SP32). Each setpoint is defined by its fixed x position and its programmable y value. The setpoint x positions (SP(n)_X) are equally distributed between –32768...32767 LSB along the signal range.

The setpoint registers have a length of 16 bits and are two's complement coded. Therefore, the setpoint Y values (SP(n)_Y) can vary between –32768...32767 LSB. For the value of the SP(n)_Y register, only the difference between the setpoint y value and the corresponding setpoint x value has to be programmed into the setpoint register. The setpoint register values are initially set to 0 (neutral) by default.

Alternatively, 17 variable setpoints can be used. In this case, the x positions are not equally distributed anymore.

In case of variable setpoints are selected, nspgain registers must be used.

The nspgain value has to be changed if one of the setpoint slopes exceeds the permitted range (setpoint slope > 1). To use nspgain correctly, the maximum slope of the graphs between two adjacent setpoints has to be determined. Then the maximum setpoint gain has to be calculated. Afterwards, nspgain is used to set the gain exponent for the setpoint slope on the data channel.

The setpoint linearization block works in a way that the incoming signal (SETPOINT_IN value) is interpolated linearly between two adjacent setpoints (SP(n) and SP(n+1)). The resulting OUT register value represents the magnetic field information after the setpoint scaling.

nsp_gain (EEPROM Settings) (only for 2Z setup)

The SETUP_DATAPATH[4:1] bits (= nspgain) set the gain exponent for the setpoint slope on data channel. With the 4 bits it is possible to get gains up to 65536.

DNC Filter Registers (dnc_–3dB_frequency & dnc_threshold) (only for 2Z setup)

The DNC (Dynamic Noise Cancellation) filter decreases the output noise significantly by adding a low-pass filter with a very low cut-off frequency for signals below a certain signal change threshold (dnc_threshold, DNC[15:8]). The attenuation factor dnc_–3dB_frequency of this FIR filter can be selected by the bits DNC[7:0] of the DNC register. Both parameters have a length of 8 bits.

Signals with a very low amplitude (signals classified as noise) and periodic movements with a low amplitude will be filtered whereas signals with a higher amplitude are untouched (i. e. rapid changes). The activation of the DNC filter has no impact on the resolution of the output and does not add any additional processing delay.

For dnc_threshold, only values from 0 to 255 are allowed. For the dnc_–3dB_frequency only cutoff frequencies up to 50% of the sample frequency (0.5 * fdecsel) are allowed. To disable the DNC filter, both registers must be set to 0.

OUT_OFFSET (only for 2Z setup)

The register OUT_OFFSET is used as the final offset scaling stage for the desired output signal. The register has a length of 16 bits and is two's complement coded.

OUT_GAIN (only for 2Z setup)

The register OUT_GAIN is used as the final gain scaling stage for the desired output signal. It can also be used to invert the output signal. The register has a length of 16 bits and is two's complement coded.

Clamping Levels (CLAMP-LOW & CLAMP-HIGH (usable in 2Z measurement setup))

The clamping levels CLAMP_LOW and CLAMP_HIGH define the maximum and minimum output values. Both registers have a length of 16 bits and are two´s complemented coded. Both clamping levels can have values between 0 % and 100 %.

Supply Voltage Supervision

As the device supports a wide supply voltage range it is beneficial to enable customer-programmable under- and overvoltage detection levels. The register UV_LEVEL defines the undervoltage detection level in mV and OV_LEVEL the overvoltage detection level. The SUPPLY_SUPERVISION register has a length of 16 bits. OV_LEVEL is using the 8 MSBs and UV_LEVEL the 8 LSBs. For both levels, 1 LSB typically equals 100 mV.

Standby Sleep Time

The STANDBY_SLEEP_TIME register defines the period in which the device is in standby. The 8 MSBs of this register define the sleep time. The sleep time is calculated by the following equation:

$$\text{Sleep time} = (n+1) \times 2\text{ms}$$

Thresholds for Low-Power Mode

The THRESHOLD_x registers define the threshold for the three different wake up sources in Low-Power Mode. The sensor compares its measurement data in the Active Phase of the Low-Power Mode with these thresholds. In case that those thresholds are exceeded the sensor will wake up the external ECU via the WAKO pin.

The table below shows the link between the THRESHOLD_X register and the signal sources. The available source also depends on the selected measurement setup.

Table 3–2: Sources for THRESHOLD_X registers

THRESHOLD_X	IPC Channel	Signal Source
0	IPC_CHAN0	COMP_CH1 (Setup 6Z) or OUT (Setup 2Z)
1	IPC_CHAN1	COMP_CH2 (Setup 6Z)
2	IPC_CHAN2	COMP_CH3 (Setup 6Z)

Additional information can also be found in Table 3–3 on page 18 and Table 3–1 on page 12.

Customer Configuration Register

The SETUP_FRONTEND, SETUP_DATAPATH, and SETUP_STANDBY registers are 16-bit register that enable the customer to activate various functions of the sensor. They also contain the lock bit to lock the sensors memory. Table 3–3, Table 3–4, and Table 3–5 describe in detail the available combinations and resulting functions.

Table 3–3: SETUP_FRONTEND

Bit No.	Function	Description
15	customer_lock	Customer Lock: 0: Unlocked 1: Locked
14:9	-	Must be set to 0.
8	cluster	0: IPC_CHAN0 to IPC_CHAN2 are independent 1: IPC_CHAN0 to IPC_CHAN2 are updated after IPC_CHAN0 is read
7:6	-	Must be set to 0.
5:4	fdecsel	A/D converter sample frequency: 00: 2 kSps 01: 4 kSps 10: 8 kSps
3:0	-	**Reserved**

Table 3–4: SETUP_DATAPATH

Bit No.	Function	Description
15:8	-	Must be set to 0
7:5	nmult	Gain exponent for SETPOINT_IN: SP_gain = SP_GAIN* [2^(nmult)]
4:1	nspgain	Gain exponent for setpoint slope: Slope = SP_gain * (2^nspgain+1)
0	var_sp	Fixed/variable setpoint selection: 0: Fixed setpoints 1: Variable setpoints

Table 3–5: SETUP_STANDBY

Bit No.	Function	Description
15:10	-	Must be set to 0
9	wakout	WAKI/O pin as wake output: 0: Disabled 1: Enabled Note: Used with internal counter wake-up. Wakes ECU via this pin if desired.
8	cnt_wakeup	Internal wake-up by sleep counter 0: Disabled 1: Enabled
7:6	ext_wakeup	Defines the behavior of the Wake-up output pin to trigger a wake-up of an external ECU: 00: Disabled 01: Rising edge 10: Falling edge 11: Rising and falling edge
5:4	thrd_2	Defines the behavior of the Wake-up output pin for changes of IPC2 channel 00: Deactivated 01: Change Wake-up output if IPC2 is above the threshold 10: Change Wake-up output if IPC2 is below the threshold 11: Reserved
3:2	thrd_1	Defines the behavior of the Wake-up output pin for changes of IPC1 channel 00: Deactivated 01: Change Wake-up output if IPC1 is above the threshold 10: Change Wake-up output if IPC1 is below the threshold 11: Reserved
1:0	thrd_0	Defines the behavior of the Wake-up output pin for changes of IPC0 channel 00: Deactivated 01: Change Wake-up output if IPC0 is above the threshold 10: Change Wake-up output if IPC0 is below the threshold 11: Reserved
Note: Low-power Mode is enabled if either ext_wakeup or cnt_wakeup are enabled.		

3.4. SPI

The CUR 4000 is equipped with an SPI (Serial Peripheral Interface) for memory programming and register reading to transmit the sensor measurement data. SPI uses four wires and a master-slave architecture for synchronous serial communication. The CUR 4000 is always acting as the slave and the ECU is the master. The SPI bus configuration with one slave is shown in Fig. 3–8.

Fig. 3–8: Description of the SPI Bus

On the 'Master Out slave In' (MOSI) wire the master sends data to the slave. On the 'Master In slave Out' (MISO) wire, the slave sends data to the master. The 'Chip Select' (CSN) is driven by the master and grants the slave and the following occurrences permission to read from and write to the bus. The CSN signal is active low. The 'Serial Clock' (SCK) signal is used by the master to establish the communication speed.

It is also possible to connect several slaves to one master. The master has to select the desired slave by pulling down the corresponding CSN line.

Each transfer is full duplex for simultaneously sending read/write commands to the sensor while collecting the response from the former request. As a part of the SPI protocol CUR 4000 defines a status byte, which delivers error and status information about the sensor with each SPI transfer. Additionally, the protocol immanent CRC secures the correct transport of bits as well as the correct execution of the requested command.

The general SPI frame format is as follows (see Fig. 3–9):

1. SPI master pulls the CSN to low,
2. SPI master sends one command byte followed by two master data bytes,
3. SPI master sends an 8-bit CRC,
4. CUR 4000 replies in the next frame with one status byte and two slave data bytes followed by a 8-bit slave CRC.

The CRC for CUR 4000 is calculated based on the following polynomial:
$X^8 + X^4 + X^3 + X^2 + 1$ (0x1D), with a seed value of 0xFF and a final XOR value of 0xFF (CRC-8-SAE-J1850).

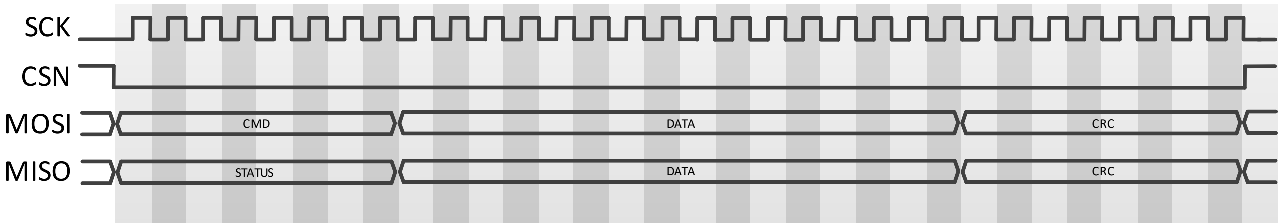


Fig. 3–9: Communication frame structure via SPI

Two communication frames are defined:

– MOSI Frame (SDI): 8-bit command (CMD), 16-bit data and 8-bit CRC (total: 32-bit)

– MISO Frame (SDO): 8-bit status (STATUS), 16-bit data and 8-bit CRC (total: 32-bit)

Note Please refer to Table 3–1 on page 12 for access to the measurement data.The DIAG0 & DIAG1 bits are only updated while reading the IPC_CHAN registers. Reading EEPROM content or RAM in programming mode will not trigger the DIAGx registers.

Write commands execute internally after the master CRC is verified. This is to guarantee no unintended register writes happens.

The command byte (CMD) contains a 7-bit word address and a RWN flag.

Table 3–6: SPI Command Byte

CMD	**Command Byte**							
	7	6	5	4	3	2	1	0
r/w	**ADR**							**RWN**

The STATUS byte of the read protocol contains several information.

Table 3–7: SPI Status Byte

STATUS	Status Byte							
	7	6	5	4	3	2	1	0
r/w	RC3	RC2	RC1	RC0	DIAG0	DIAG1	CRC ERR	NEW

– RC[3:0]: Rolling counter keeps track of the communication frames being sent between SPI master and sensor. It is incremented by one with each communication frame from 1 to 15. Then it restarts at 1 again (reset value = 0),

– DIAG0: This bit is set to one in case an error has been indicated in DIAGNOSIS_0 register (see Table 4–1 on page 28),

– DIAG1: This bit is set to one in case an error has been indicated in DIAGNOSIS_1 register (see Table 4–2 on page 29),

– CRCERR: Is set to one in case an error has been detected during CRC-check of previous MOSI frame,

– NEW: New sample indication (in case of an already read sample is sent multiple times the bit is set to 0).

The CRC is the last byte of any transmission and covers the preceding number of bytes. The received and transmitted streams have their own CRC byte. CRC check of the MOSI frame is done every time, independently of a read/write command. Write commands are executed internally after the master CRC is verified. This guarantees that no unintended register write happens. Read commands are executed internally before the master CRC is verified. An invalid CRC indicates a detected transmission error (signaled by CRCERR = 1 in the STATUS byte). In case of a transmission error, the status byte (transmitted in the next frame) gives feedback to the master via this CRCERR bit.

Table 3–8: SPI CRC Byte

CRC	CRC Byte							
	7	6	5	4	3	2	1	0
r/w	CRC							

Note Further details about the communication with the sensor can be found in the document: CUR 4000 Programming Guide

3.5. Low-Power Mode

Beside the Application Mode in which the device is running continuously, it also supports five different modes for power consumption reduction. These five Low-Power Modes are split into a Sleep Phase with very low current consumption and an Active Phase in which the device is performing defined measurement tasks. By setting dedicated EEPROM bits, the customer or the ECU can select between the different modes (see Table 3–5 on page 19).

The following Table describes the different use cases (UC):

Table 3–9: Overview of Low-Power Mode Use Cases

UC	ECU Mode	Sensor Tasks	ECU Tasks	Configuration of SETUP_STANDBY register (Table 3–5)
1	Controls the status of the sensor (Sleep Phase or Active Phase)	Check status of WAKI/O and start measurements after wake up	Wake up sensor by WAKI/O pin. Poll SPI read until NEW bit is set. Send sensor to Sleep Phase by SPI Command.	ext_wakeup = 01, 10 or 11. All other bits set to 0.
2	Always active and sensor is periodically in Sleep Phase.	Wake up by internal sleep counter and indicates start of Active Phase to ECU on WAKI/O pin.	Polls SPI read for NEW bit after indication of Active Phase on WAKI/O pin. Send sensor to Sleep Phase by SPI Command	cnt_wakeup = 1 wakout = 1 All other bits set to 0.
3	Is operated in Low-Power Mode until wake up by the sensor via WAKI/O pin	Wake up by internal sleep counter and indicates start of Active Phase to ECU on WAKI/O pin.	Polls SPI read for NEW bit after indication of Active Phase on WAKI/O pin. Send sensor to Sleep Phase by SPI Command.	cnt_wakeup = 1 wakout = 1 All other bits set to 0.
4		Wake up by internal sleep counter. Compare measurement with a defined threshold and wake up ECU by WAKI/O pin if threshold condition is fullfilled, else go back to Sleep Phase	Polls SPI read for NEW bit after wake up by sensor. Send sensor to Sleep Phase by SPI Command.	cnt_wakeup = 1 wakout = 1 thrd_x = 01 or 10 All other bits set to 0.
5	Is operated in Low-Power mode until wake up by the sensor via WAKI/O pin or actively wake up the sensor.	Wake up by internal sleep counter (like UC3 & 4) or wake up by external trigger on WAKI/O pin.	Wake-up sensor by WAKI/O pin or wait for wake up by the sensor. Poll SPI read for NEW bit. Send sensor to Sleep Phase by SPI Command	cnt_wakeup = 1 ext_wakeup = 01,10 or 11 wakout = 1 thrd_x = 01 or 10

Note To wake up the sensor by the ECU in UC5, it is mandatory that the ECU is generating minimum two edges on the WAKI/O pin. Otherwise, it might happen that the sensor is missing the wake-up signal from the ECU.

3.5.1. Low-Power Mode – Use Case 1

In this use case, the ECU is taking over the full control for the sensor Low-Power Mode. The ECU can send the sensor into the Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will stay in the Sleep Phase until the ECU generates a signal change on the WAKI/O pin of the sensor. The sensor will then start its initialization phase and move to active mode in order to start the first measurement. The ECU will then have to poll read command for a valid NEW bit in the SPI protocol status byte. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase.

This mode is enabled by setting the ext_wakeup bits in the SETUP_STANDBY register. These bits define what kind of signal edge is used to wake up the sensor on the WAKI/O pin.

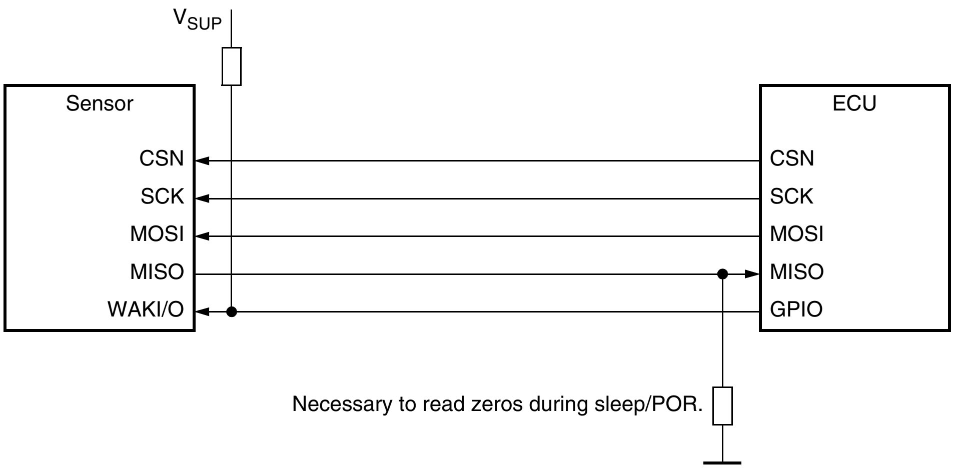


Fig. 3–10: Wake up of sensor via WAKI/O pin

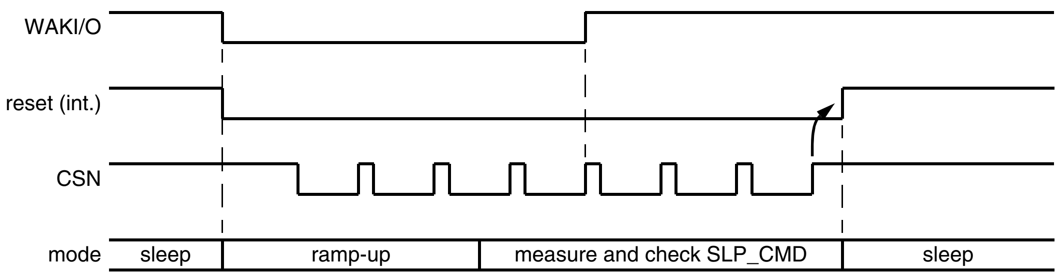


Fig. 3–11: Timing diagram for Low-Power Mode use case 1

3.5.2. Low-Power Mode – Use Case 2 and 3

In these two use cases, the sensor and the ECU control together the Low-Power Mode. The sensor will stay in the Sleep Phase for a defined time. This time is defined by the STANDBY_SLEEP_TIME register. After this time has elapsed, the sensor will start its initialization phase and move to Active Mode in order to start the first measurement. By changing the status of the WAKI/O pin it will indicate to the ECU that the Active Mode has been started. The ECU will then have to poll read commands for a valid NEW bit in the SPI protocol status byte. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will then start the next sleep cycle.

The ECU can stay continuously awake to execute other tasks or it can go to Low-Power Mode as well waiting for a wake-up trigger from the sensor via the WAKI/O pin.

This mode is enabled by setting the wakout bit and the cnt_wakeup bit in the SETUP_STANDBY register.

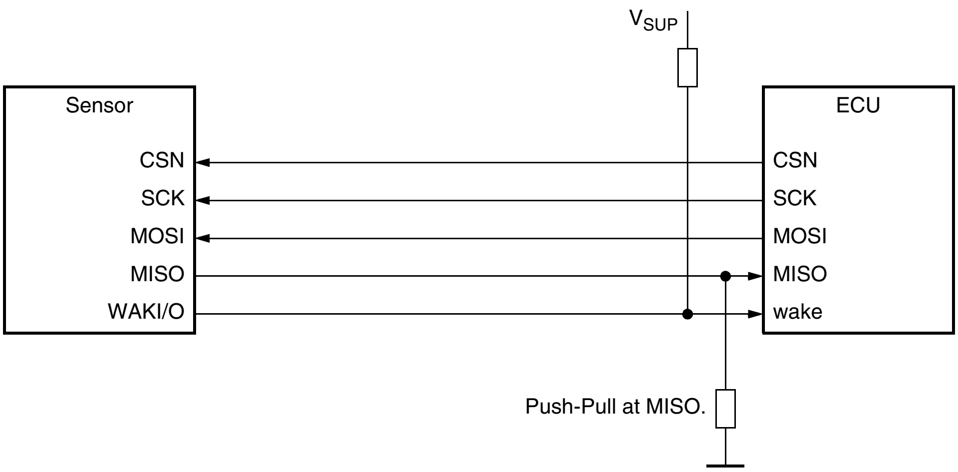


Fig. 3–12: Wake up of sensor by counter and Active Mode indication on WAKI/O pin

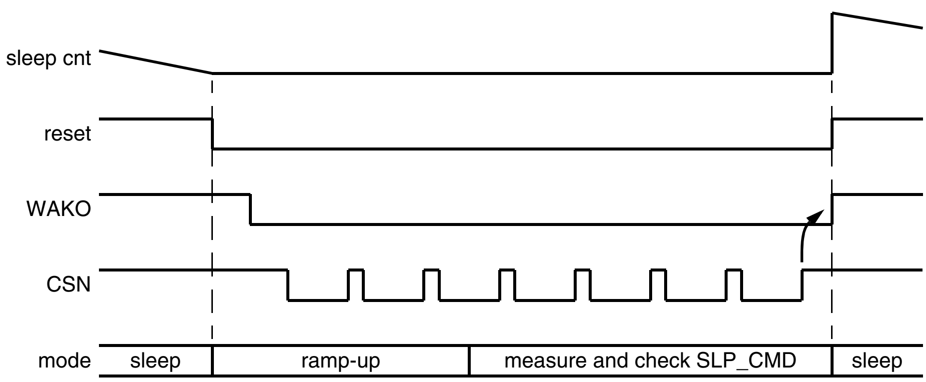


Fig. 3–13: Timing diagram for Low-Power Mode use case 2 &3

3.5.3. Low-Power Mode – Use Case 4

In this use case, the sensor has the full control of the Low-Power Mode. The sensor will stay in the Sleep Phase for a defined time. This time is defined by the STANDBY_SLEEP_TIME register. After this time has elapsed, the sensor will start its initialization phase and move to Active Mode in order to start the first measurement. In this Active Mode the sensor compares the measurement result with up to three defined thresholds. The threshold values are defined by the THRESHOLD_x registers (see page 17). The sensor will go back to sleep if no threshold is exceeded. The sensor will change the status of the WAKI/O pin to inform the ECU in case that a threshold has been exceeded. The ECU will then have to poll read commands for a valid NEW bit in the SPI protocol status byte. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will then start the next sleep cycle.

This mode is enabled by setting the wakout bit, the cnt_wakeup bit and at least one of the thrd_x bits in the SETUP_STANDBY register.

Fig. 3–12 and Fig. 3–13 on page 25 are also valid for this mode in addition the WAKI/O pin is only changed if one of the selected thresholds has been exceeded.

3.5.4. Low-Power Mode – Use Case 5

This use case is a combination of the use cases 1 and 4. The sensor can trigger a wake-up at the ECU side, but the ECU can also trigger a wake-up of the sensor while it is in Sleep Phase. Fig. 3–10 shows the required external wiring for this specific mode.

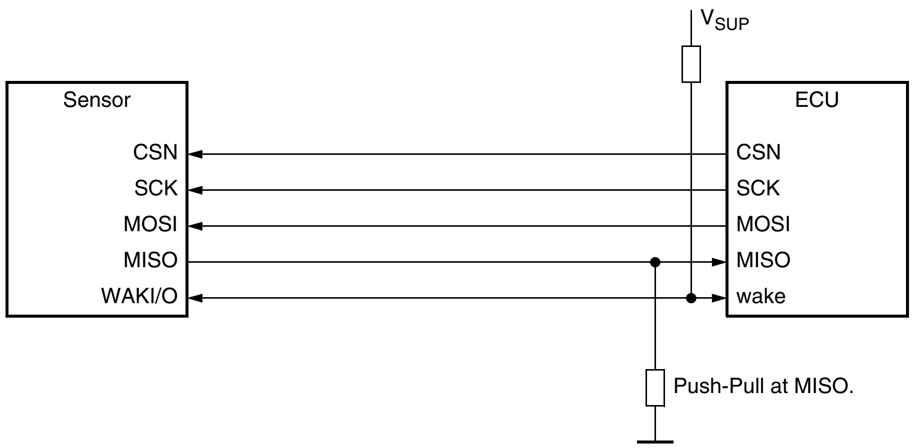


Fig. 3–14: Wake up of sensor by counter and WAKI/O pin and Active Mode indication

For this case, it does not matter if the sensor or the ECU or both at the same time are triggering a wake-up. The sensor is running its measurement cycle and the ECU polls for the NEW bit by reading the sensor output signal via SPI. After the ECU has read the necessary amount of measurement data it can send the sensor back into Sleep Phase by sending the Go-to-Sleep Command 0xA55A to IPC_CHAN3 register. The sensor will then start the next sleep cycle.

This mode is enabled by setting the wakout bit, the cnt_wakeup bit, ext_wakeup bits and at least one of the thrd_x bits in the SETUP_STANDBY register.

Note To wake up the sensor by the ECU in use case 5, it is mandatory that the ECU is generating minimum two edges on the WAKI/O pin. Otherwise, it might happen that the sensor is missing the wake-up signal from the ECU.

4. Functional Safety

4.1. Functional Safety Manual and Functional Safety Report

The Functional Safety Manual for CUR 4000 contains the necessary information to support customers to realize a safety-compliant application by integrating CUR 4000 as an ASIL B ready component into their system. The Functional Safety Manual will be provided upon request.

The Functional Safety Report describes the assumed Safety Goal, the corresponding Failure Modes as well as the Base Failure Rate for die and package according to IEC TR 62380. It can be provided based on a TDK-Micronas mission profile as well as customer mission profiles.

4.2. Integrated Diagnostic Mechanism

CUR 4000 performs self-tests during start-up and normal operation. These increase the robustness of the device functionality by either preventing the sensor to provide wrong output signals or by reporting a failure via the status byte in the SPI frame.

Detailed result of the internal diagnostics is available via the DIAGNOSIS_X registers. Both registers can be read via the SPI interface.

Table 4–1: DIAGNOSIS_0 register

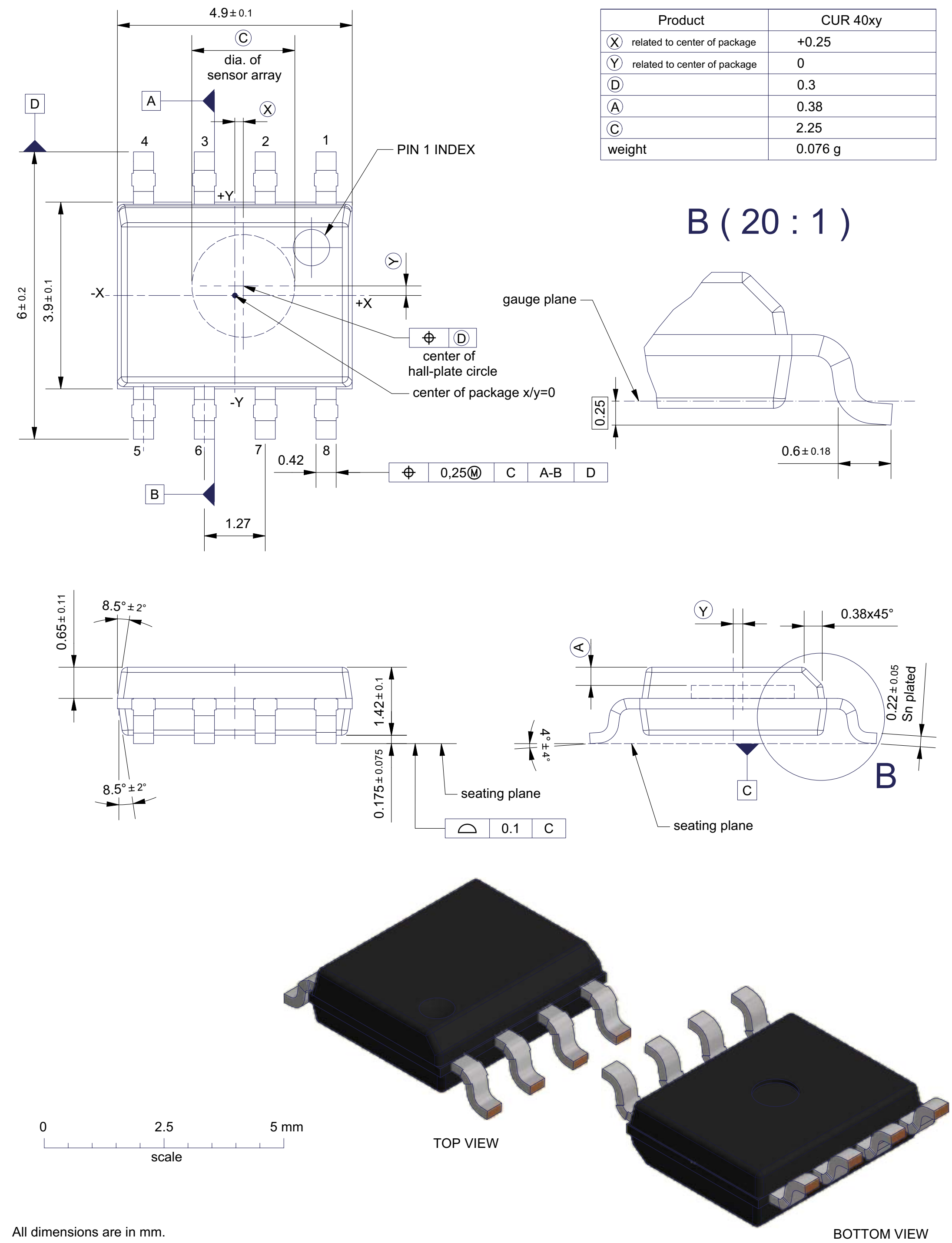
Bit no.	Description when bit is set to 1
15	DSP self-check routines (redundancy or plausibility checks)
14	DSP and µC check of 16-bit checksum covering the EEPROM parameter
13	DSP checksum for ROM and RAM
12	Chip junction temperature out of range
11	Plausibility check of redundant temperature sensor
10	Hall-plate supply too high
9	Hardware overtemperature supervision: Junction temperature > 180°C
8	Reserved
7	At least one of the A/D converters delivers a stuck signal for Channel 1, 2, or 3
6	Overflow or underflow of decimation filter
5	MAG_HIGH threshold has been exceeded (can be used for overcurrent detection in 6Z measurement setup)
4	MAG_LOW threshold has been exceeded
3	CLMP_HI threshold has been exceeded (can be used for positive overcurrent detection in 2Z measurement setup)
2	CLMP_LO threshold has been exceeded (can be used for positive overcurrent detection in 2Z measurement setup)
1	Hall-plate current out of range
0	Reserved

Table 4–2: DIAGNOSIS_1 register

Bit no.	Description when bit is set to 1
15	Reserved
14 & 12	General-purpose ADC error
13	Reserved
11	Undervoltage Error. Supply voltage out of range
10	Overvoltage Error. Supply voltage out of range.
9	Internal analog voltage out of range
8	Internal digital voltage out of range
Note: Bits{7:0] cannot be read via the programming interface as they are triggering immediately a reset of the device.	
7	µC self-test error
6	µC ROM OP code error
5	µC memory OP code error
4:2	Reserved
1	Error in analog part
0	Reserved

5. Specifications

5.1. Outline Dimensions

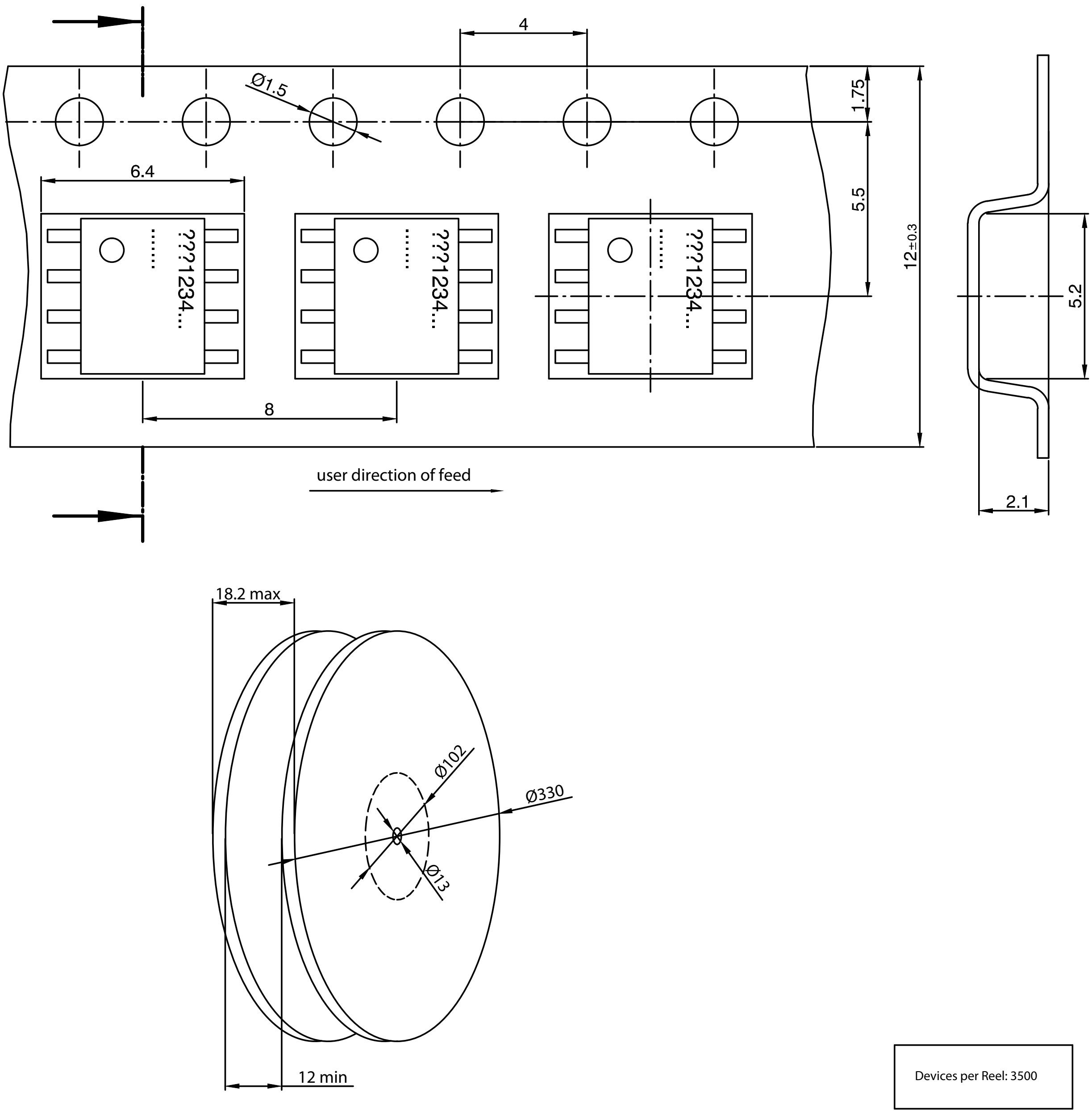


Product	CUR 40xy
X related to center of package	+0.25
Y related to center of package	0
D	0.3
A	0.38
C	2.25
weight	0.076 g

All dimensions are in mm.
Physical dimensions do not include moldflash.
Sn-thickness might be reduced by mechanical handling.

PACKAGE	ISSUE DATE (YY-MM-DD)	JEDEC STANDARD		ANSI	REVISION DATE (YY-MM-DD)	REV.NO.	DRAWING-NO.	SPECIFICATION	
		ITEM NO.	ISSUE					TYPE	NO.
SOIC8-1	20-11-04	MS-012	F		20-11-04	1	CSOIC0083013.1	ZG	2118_Ver.01

Fig. 5–1:
SOIC8-1: Plastic **S**mall **O**utline **IC** package, 8 leads, gullwing bent, 150 mil
Ordering code: DJ



IEC STANDARD		ANSI	ISSUE DATE YY-MM-DD	DRAWING-NO.	ZG-NO.
ISSUE	ITEM NO.				
4th	60286-3		12-01-31	06836.0001.4	ZG002036_001_01

Fig. 5–2:
SOIC8-1: Dimensions Tape & Reel

5.2. Soldering, Welding, Assembly

Information related to solderability, welding, assembly, and second-level packaging is included in the document “Guidelines for the Assembly of Micronas Packages”.
It is available on the TDK-Micronas website (https://www.micronas.com/en/service-center/downloads) or on the service portal (http://service.micronas.com).

5.3. Storage and Shelf Life Package

Information related to storage conditions of TDK-Micronas sensors is included in the document “Guidelines for the Assembly of Micronas Packages”. It gives recommendations linked to moisture sensitivity level and long-term storage.
It is available on the TDK-Micronas website (https://www.micronas.com/en/service-center/downloads) or on the service portal (http://service.micronas.com).

5.4. Size and Position of Sensitive Areas

Diameter of sensitive area: C = 2.25 mm

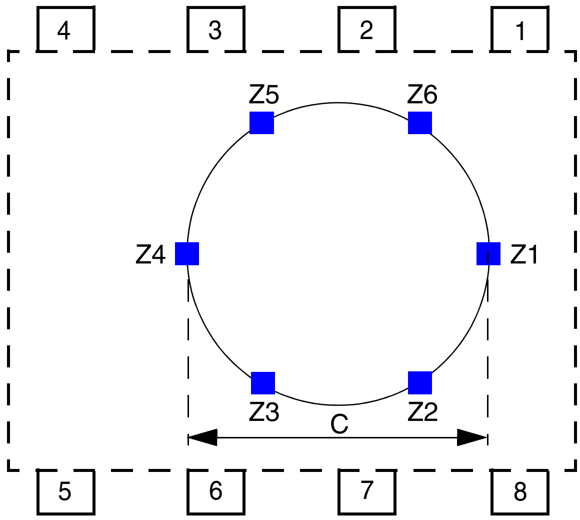


Fig. 5–3: Hall-plate configuration

5.5. Definition of Magnetic-Field Vector

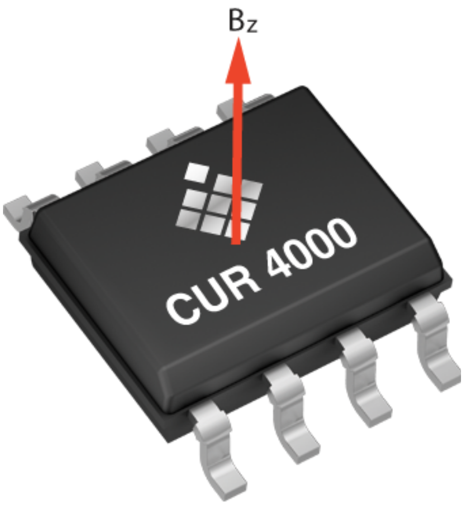


Fig. 5–4: Definition of magnetic-field vector for CUR 4000

5.6. Pin Connections and Short Description

Table 5–1: Pin connection SOIC8

Pin No.	Pin Name	Type	Short Description
1	VSUP	IN	Supply Voltage
2	GND	GND	Ground
3	TEST	N/A	Test
4	CSN	I/O	SPI Chip-Select
5	MISO	OUT	SPI Out
6	WAKI/O	I/O	Wake Up
7	MOSI	IN	SPI In
8	SCK	IN	SPI Clock

Note Pins 2 and 3 must be connected to GND.

5.7. Absolute Maximum Ratings

Stresses beyond those listed in the “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only. Functional operation of the device at these conditions is not implied. Exposure to absolute maximum rating conditions for extended periods will affect device reliability.

This device contains circuitry to protect the inputs and outputs against damage due to high static voltages or electric fields; however, it is advised that normal precautions must be taken to avoid application of any voltage higher than absolute maximum-rated voltages to this high-impedance circuit.

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin Name	Min.	Max.	Unit	Condition
V_{SUP}	Supply Voltage	VSUP	–18	28	V	
			–	37	V	t < 60s; T_A=50°C
V_{IN_WAKIO}	Input Voltage WAKI/O Pin	WAKIO	–0.3	6	V	t < 96 h
V_{IN}	Input Voltage SPI Pins	CSN, MOSI, SCK	–0.3	VSUP +0.3V	V	t < 96 h
V_{OUT_MISO}	Output Voltage MISO Pin	MISO	–0.3	VSUP	V	t < 96 h
V_{OUT_MISO}– V_{SUP}	Excess of MISO Output Voltage over VSUP	MISO	–	0.3	V	t < 96 h
B_{max}	Magnetic Field	–	–	1	T	
T_A	Ambient Temperature	–	–40	160	°C	[1)]
T_J	Junction Temperature	–	–40	190	°C	t < 96 h [2)]
$T_{storage}$	Transportation/ Short Term Storage Temperature	–	–55	150	°C	Device only without packing material
V_{ESD}	ESD Protection	VSUP, MISO, CSN, SCK, MOSI, WAKIO, TEST	–2	2	kV	[3)]

[1)] Consider current consumption, molding condition (e.g. overmold, potting) and mounting situation for T_A and in relation to T_J
[2)] Please contact TDK-Micronas for other temperature requirements
[3)] AEC-Q100-002 (100 pF and 1.5 kΩ)
No cumulative stress for all parameter

5.8. Recommended Operating Conditions

Functional operation of the device beyond those indicated in the "Recommended Operating Conditions/ Characteristics" is not implied and may result in unpredictable behavior, reduced reliability and lifetime of the device.

All voltages listed are referenced to ground (GND).

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Condition
V_{SUP}	Supply Voltage	VSUP	3.0	–	5.5	V	
V_{IN_WAKIO}	Input Voltage	WAKIO	0	–	5	V	
R_{WAKIO}	Load Resistance on WAKI/O Pin	WAKIO	10	100	–	kΩ	Pull-up
R_{SPI_LOAD}	Total Load Resis- tance	MISO	10	–	–	kΩ	Pull-down
C_{SPI_LOAD}	Total Load Capacitance	MISO	6	–	100	pF	$f_{SPI} \leq$ 5MHz
N_{PRG}	Number of Memory Programming Cycles	–	–	–	100	cycles	0 °C < T_{amb} < 55 °C
B_{AMP}	Recommended Magnetic Field Amplitude	–	–	–	±100	mT	
T_J	Junction Temperature		–40	–	170	°C	For 1000 h [1)]
T_A	Ambient Temperature		–40	–	150	°C	[2)]

[1)] Depends on the temperature profile of the application. Please contact TDK-Micronas for life time calculations.
[2)] Consider current consumption, mounting condition (e.g. overmold, potting) and mounting situation for T_A and in relation to T_J

5.9. Characteristics

at T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 5.5 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Test Conditions”.
Typical Characteristics for T_A = 25 °C and V_{SUP} = 5 V.

Symbol	Parameter	Pin Name	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
I_{SUP}	Supply Current	VSUP	–	8	12	mA	1)
I_{SUP_SM}	Supply Current in Standby Mode	VSUP	–	–	15	µA	While IC is in sleep phase T_A = 25 °C
$t_{startup}$	Start-up Time	MISO	–	–	10	ms	1)
f_{osc}	Internal Oscillator Frequency	–	–	32	–	MHz	
f_{sample}	Sampling Frequency	–	–	8	–	kSps	Configurable
Power-On behavior							
V_{POR}	Power-on Reset Voltage	VSUP	2.1	2.6	2.9	V	
$V_{PORHyst}$	Power-on Reset Voltage Hysteresis	VSUP	–	200	–	mV	
Overvoltage and Undervoltage Detection							
$S_{VSUP,UOV}$	Step Size of Under-/Overvoltage Supervision Threshold	VSUP	92	100	108	mV/LSB	1) Under-/Overvoltage threshold is customer configurable
$S_{SUP,UOVhyst}$	Under-/Overvoltage Detection Level Hysteresis	VSUP	–	1	–	LSB	1) 1 LSB typ. 100 mV
SPI Characteristics							
V_{IH}	Input High Level	MOSI, SCK, CSN	2.4	–	–	V	
V_{IL}	Input Low Level	MOSI, SCK, CSN	–	–	0.8	V	
V_{OH}	Output High Level	MISO	V_{SUP} –0.6	–	–	V	I_{OUT} = –10 mA
V_{OL}	Output Low Level	MISO	–	–	0.6	V	I_{OUT} = 20 mA
I_{OShort_Low}	MISO Output Current for Short to GND	MISO	–50	–40	–30	mA	$V_{SUP} > V_{OUT}$ > GND
I_{OShort_High}	MISO Output Current for Short to V_{SUP}	MISO	25	40	50	mA	$V_{SUP} > V_{OUT}$ > GND
R_{PD}	Pull-down resistor	MOSI, SCK	35	–	120	kΩ	internal Pull-down resistor refers to GND
R_{PU}	Pull-up resistor	CSN	35	–	120	kΩ	internal Pull-up resistor refers to V_{SUP}
I_{OLEAK}	Leakage Current	MISO	–2	–	2	µA	

Symbol	Parameter	Pin Name	Limit Values			Unit	Test Conditions
			Min.	Typ.	Max.		
t_{SCK}	SPI Clock Period	SCK	200	1000	–	ns	1) Max. frequency 5 MHz
t_{DIS}	SPI Data Input Setup	MOSI, SCK	10	–	–	ns	1) Data sampling with rising SCK edge
t_{DIH}	SPI Data Input Hold	MOSI, SCK	15	–	–	ns	1)
t_{DOD}	SPI Data Output Delay	MISO, SCK	–	–	44	ns	1) Data output changes with falling SCK edge
t_{SSC}	SPI CSN setup time	CSN, SCK	80	–	–	ns	1) With respect to falling CSN edge
t_{SCS}	SPI CSN Hold Time	CSN, SCK	12	–	–	ns	1) With respect to the rising CSN edge
t_{SCH}	SPI CSN High Time	CSN	2* t_{SCK}	2000 s	–	ns	1) CSN high time between two consecutive SPI frames
t_{set}	SPI Settling Time	–	–	4	–	ms	1)
t_{listen}	Waiting Time for the Programming Mode Command	–	–	–	110	ms	1) Waiting for data 0x2EAE to address 0x75 after power on
SOIC8 Package							
							(Self-heating calculation see Section 6.1. on page 40)
R_{thja}	Thermal Resistance Junction to Air	–	–	–	140	K/W	2) Determined with a 1S0P board
		–	–	–	93	K/W	2) Determined with a 2S2P board
R_{thjc}	Thermal Resistance Junction to Case	–	–	–	33	K/W	2) Determined with a 1S0P & 2S2P board

1) Characterized on small sample size, not tested.
2) Self-heating calculation see Section 6.1

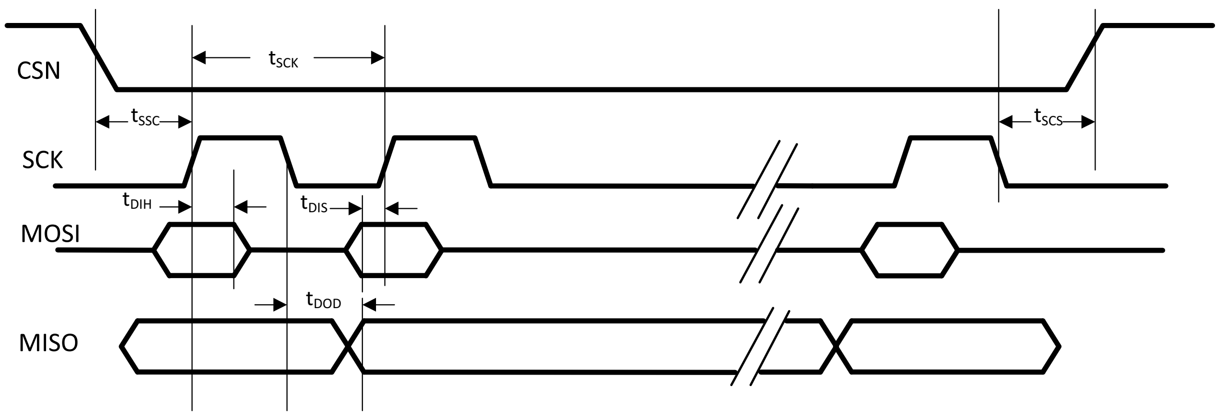


Fig. 5–5: SPI timing diagram

5.10. Magnetic Characteristics

At T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 5.5 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column "Test Conditions". Typical Characteristics for T_A = 25 °C and V_{SUP} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Test Conditions
Signal channels Z4+Z1 (additive)							
$Sense_{Z4+Z1}$	Sensitivity of Z4+Z1 Channel	MISO	251	256	261	LSB_{15} /mT	[1] T_A = 25 °C
$\Delta Sense_{Z4+Z1}$	Thermal Sensitivity Drift of Z4+Z1 Channel	MISO	–1.5	–	1.5	%	[1] Related to T_A = 25 °C
$\Delta Sense_{Z4+Z1life}$	Sensitivity Drift of Z4+Z1 Channel over life time	MISO	–0.6	–	0.6	%	[1] After 1000 h HTOL T_A = 25 °C
$Offset_{Z4+Z1}$	Offset of Z4+Z1 Channel	MISO	–30	–	30	LSB_{15}	[1] T_A = 25 °C
$\Delta Offset_{Z4+Z1}$	Thermal Offset Drift of Z4+Z1 Channel	MISO	–20	–	20	LSB_{15}	[1] Related to T_A = 25 °C
$\Delta Offset_{Z4+Z1life}$	Offset Drift of Z4+Z1 Channel over life time	MISO	–8	–	8	LSB_{15}	[1] After 1000 h HTOL T_A = 25 °C
$NonLin_{Z4+Z1}$	Non-Linearity of Z4+Z1 Channel	MISO	–0.1	–	0.1	%	[5]
$Noise_{Z4+Z1}$	Noise of Z4+Z1 Channel	MISO	–	2.3	–	LSB_{15}	[2] T_A = 25 °C
Signal channels Z4-Z1 (differential)							
$Sense_{Z4-Z1}$	Sensitivity of Z4-Z1 Channel	MISO	125	128	131	LSB_{15} /mT	[4] T_A = 25 °C
$\Delta Sense_{Z4-Z1}$	Thermal Sensitivity Drift of Z4-Z1 Channel	MISO	–1.8	–	1.8	%	[4] Related to T_A = 25 °C
$\Delta Sense_{Z4-Z1life}$	Sensitivity Drift of Z4-Z1 Channel over life time	MISO	–0.7	–	0.7	%	[4] After 1000 h HTOL T_A = 25 °C
$Offset_{Z4-Z1}$	Offset of Z4-Z1 Channel	MISO	–35	–	35	LSB_{15}	[1] T_A = 25 °C
$\Delta Offset_{Z4-Z1}$	Thermal Offset Drift of Z4-Z1 Channel	MISO	–15	–	15	LSB_{15}	[1] Related to T_A = 25 °C
$\Delta Offset_{Z4-Z1life}$	Offset Drift of Z4-Z1 Channel over life time	MISO	–6	–	6	LSB_{15}	[1] After 1000 h HTOL T_A = 25 °C
$NonLin_{Z4-Z1}$	Non-Linearity of Z4-Z1 Channel	MISO	–0.1	–	0.1	%	[5]
$Noise_{Z4-Z1}$	Noise of Z4-Z1 Channel	MISO	–	2.6	–	LSB_{15}	[2] T_A = 25 °C
SFR_{Z4-Z1}	Stray-Field Rejection of Z4-Z1 Channel	MISO	96	–	–	%	[3] T_A = 25 °C
Signal channels 6Zavg (Average of Z1+Z4, Z2+Z5, Z3+Z6)							
$Sense_{6Zavg}$	Sensitivity of 6Zavg Channel	MISO	251	256	261	LSB_{15} /mT	[1] T_A = 25 °C
$\Delta Sense_{6Zavg}$	Thermal Sensitivity Drift of 6Zavg Channel	MISO	–1.2	–	1.2	%	[1] Related to T_A = 25 °C
$\Delta Sense_{6Zavglife}$	Sensitivity Drift of 6Zavg Channel over life time	MISO	–0.4	–	0.4	%	[1] After 1000 h HTOL T_A = 25 °C

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Test Conditions
$Offset_{6Zavg}$	Offset of 6Zavg Channel	MISO	–20	–	20	LSB_{15}	[1] T_A = 25 °C
$\Delta Offset_{6Zavg}$	Thermal Offset Drift of 6Zavg Channel	MISO	–12	–	12	LSB_{15}	[1] Related to T_A = 25 °C
$\Delta Offset_{6Zavglife}$	Offset Drift of 6Zavg Channel over life time	MISO	–4	–	4	LSB_{15}	[1] After 1000 h HTOL T_A = 25 °C
$NonLin_{6Zavg}$	Non-Linearity of 6Zavg Channel	MISO	–0.1	–	0.1	%	[5]
$Noise_{6Zavg}$	Noise of 6Zavg Channel	MISO	–	1.4	–	LSB_{15}	[2] T_A = 25 °C

1) Characterized on small sample size, 3-sigma values, not tested for each device
2) Characterized on small sample size, 1-sigma values, sampling frequency= 2kHz, Low-pass filter: off
3) Characterized on small sample size according to ISO 11452-8:2015, at 25 °C, with stray-field strength of 4 kA/m from Z direction, 3-sigma values (not tested)
4) Based on simulation model (not tested)
5) Characterized on small sample size with B_{AMP} = ±90mT, 3-sigma values, not tested for each device

5.11. Temperature Sensor

At T_A = –40 °C to 150 °C, V_{SUP} = 3.0 V to 5.5 V, GND = 0 V, after programming and locking of the sensor, at Recommended Operation Conditions if not otherwise specified in the column “Test Conditions”.
Typical Characteristics for T_A = 25°C and V_{SUP} = 5.0 V.

Symbol	Parameter	Pin Name	Min.	Typ.	Max.	Unit	Test Conditions
$TADJ_{Gain}$	Gain of Temperature Sensor	MISO	–	89.25	–	LSB_{15} /°C	[1]
$TADJ_{Offset}$	Temperature Sensor Offset	MISO	–	3720	–	LSB_{15}	[1]
ΔT_{Lin}	Temperature Sensor Differential Accuracy (Linearity Error)	MISO	–2	0	2	°C	[1]
ΔT_{Offset}	Temperature Sensor Offset Error	MISO	–5	0	5	°C	[1]

1) Characterized on small sample size, 3-Sigma values, not tested for each device

6. Application Notes

6.1. Ambient Temperature

Due to the internal power dissipation, the temperature on the silicon chip (junction temperature T_J) is higher than the temperature outside the package (ambient temperature T_A).

$T_J = T_A + \Delta T$

The maximum ambient temperature is a function of power dissipation, maximum allowable die temperature and junction to ambient thermal resistance (R_{thja}). With a typical supply voltage of 3.3 V the power dissipation P is 0.04 W per die. The junction to ambient thermal resistance R_{thja} is specified in Section 5.9. on page 36.

The difference between junction and ambient air temperature is expressed by the following equation (at static conditions and continuous operation):

$\Delta T = P * R_{thjX}$

The X represents junction to air, case or solder point.

For worst case calculation, use the max. parameters for I_{SUP} and R_{thjX}, and the max. value for V_{SUP} from the application.

Note The calculated self-heating of the device is only valid for the Rth test boards. Depending on the application setup the final results in an application environment might deviate from these values.

6.2. EMC and ESD

Please contact TDK-Micronas for detailed information on EMC and ESD performance.

6.3. Application Circuit for CUR 4000

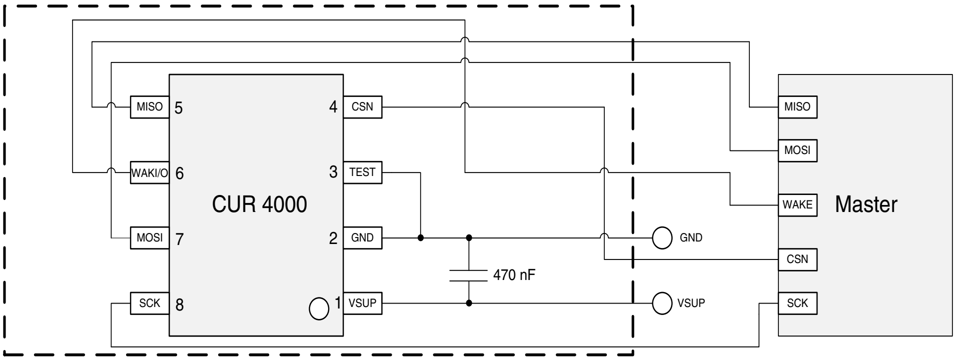


Fig. 6–1: Recommended application circuit for CUR 4000 (one slave and one master)

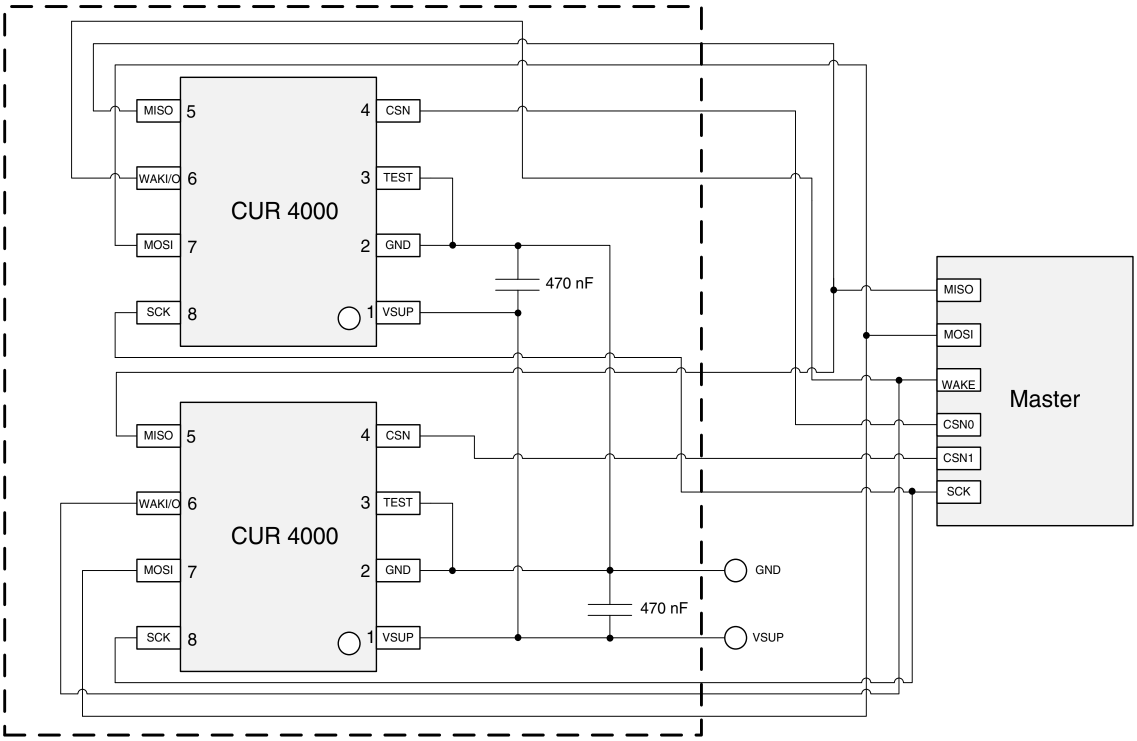


Fig. 6–2: Recommended application circuit for CUR 4000 (two slaves and one master)

6.4. Recommended Pad Size SOIC8 Package

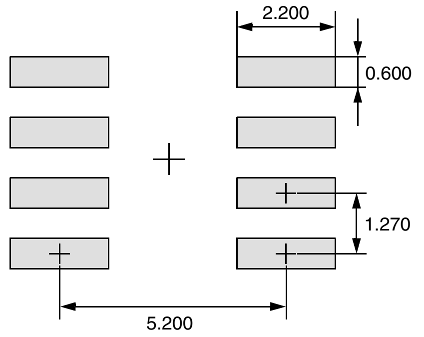


Fig. 6–3: Pad size recommendation for SOIC8 package (all dimensions in mm)

7. Programming of the Sensor

CUR 4000 features two different customer modes. In **Application Mode** the sensor provides digital output data via SPI interface. In **Programming Mode** it is possible to change the register settings of the sensor.

After power-up the sensor is always operating in the **Application Mode**. It is switched to **Listening Mode** by writing the data 0x22A2 to address 0x75 (IPC_CHAN5). The sensor will remain in listening mode for max. 110 ms (t_{listen}). During this period the sensor can be switched to **Programming Mode** by writing the data 0x2EAE to address 0x75 (IPC_CHAN5). After max. 110 ms without receiving the programming mode switch command the sensor will go into reset.

7.1. Programming Interface

The sensor is programmable via the SPI interface. The standard write and read commands can be used to configure the sensors memory.

7.2. Programming Environment and Tools

For the programming of CUR 4000 during product development a programming tool including hardware and software is available on request. It is recommended to use the TDK-Micronas tool kit (TDK SPI Programmer V1.x and LabVIEW™ Programming Environment) in order to facilitate the product development. It is also possible to use a standard microcontroller to configure the device. The details of programming sequences are content of the User Manual.

7.3. Programming Information

For production and qualification tests, it is mandatory to set the LOCK bit to one after final adjustment and programming of CUR 4000.

Before locking the device, it is recommended to read back all register values to ensure that the intended data is correctly stored in the sensor's memory. Alternatively, it is also possible to cross-check the sensor output signal with the intended output behavior.

The success of the LOCK process shall be checked by reading the status of the LOCK bit after locking.

Even after locking the device it is still possible to read the memory content.

Electrostatic Discharge (ESD) may disturb the programming pulses. Please take precautions against ESD.

Note A description of the communication protocol and the programming of the sensor is available in a separate document CUR 4000 Programming Guide.

8. Document History

1. Advance Information: “CUR 4000 High-Precision Multi-Hall Array Current Sensor”, Nov. 24, 2020, AI000228_001EN. First release of the advance information
2. Data Sheet: “CUR 4000 High-Precision Multi-Hall-Array Current Sensor”, July 6, 2021, DSH000217_001EN. First release of the data sheet.

   Major changes:

   – Magnetic characteristics updated

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